Testing of Carbon Fibres as Tool Electrodes in Micro Electrical Discharge Machining

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Abstract:

The aim of this paper is to present the outcomes of the experiments concerning micro electrical discharge machining with the use of carbon fibres as tool electrodes. Key properties of carbon fibres are discussed and the procedure of such electrodes fabrication is also described. Conducted tests indicate promising perspectives for machining with such electrodes by means of shaping microcavities, but at the same time they reveal problems. A longitudinal machining as well as experiments with different electric parameters were presented. Finally, the influence of discharge energy is being considered.

Keywords: *electrical discharge machining (EDM), micromachining, carbon fibres electrodes.*

1. Introduction

Materials used in the process of Micro Electrical Discharge Machining (µEDM) are the same as the materials used in EDM e.g. tungsten, sintered tungsten carbides, sometimes also copper, brass, graphite and various composites even based on diamond [1]. Nonetheless, the procedure of application of these materials into a micro scale is needed. Sometimes special preparations must be undertaken to produce microelectrodes [2]. While searching for materials, which could be used in this process, it is essential to pay attention to some key properties that are required. Among them are: especially good electrical conductivity, thermal and wear resistance in electrical discharge conditions. Thus, the usage of carbon fibre seems to be adequate for described purpose. Primarily the evaluation of a possible use of carbon fibres as tool electrodes in EDM was described in paper [3].

2. Important properties of carbon fibres with regard to their application in EDM

The carbon fibres are well known for their very good mechanical properties. They are often used to produce carbon fibre reinforced composites. Because of this, they can be used to replace metals in many uses. The carbon fibres have diameters between 5 and 10 micrometers. They are mainly made of polyacrylonitrile (PAN) filaments as a precursor by its oxidation and pyrolysis. The whole process of how the carbon fibre is made is extremely complex and long. The main process operations of PAN precursor are thermal cyclization (ring closure) and dehydrogenation that consists of replacing CH groups with C atoms and CH_2 with CH groups. At the end of the processing the carbon fibre (or graphite fibre) is composed of carbon atoms, which are bonded together in chains and aligned along the axis of the fibre. A percentage of carbon in the final fibre varies from 92 up to almost 100 per cent. Carbon fibres can be also made of other precursors such as pitch or cellulose. The process of receiving filaments from these precursors is likewise a very complex one and the properties of obtained products are strongly determined by an applied procedure. Taking into consideration a process of EDM the most important properties are: electrical resistivity, heat stability, thermal conductivity or heat capacity. Selected properties of carbon fibres are presented in Table 1.

Table 1. Properties of carbon fibres.

Property Symbol [Unit]	Young's modulus E [GPa]	Tensile strength R_m [GPa]	Electric resistivity ρ_R [Ωm]	Heat stability T [°C]
Value	230-490	~3	$0.18 \cdot 10^{-8}$	3000 *)

**) in protective atmosphere or in vacuum, sublimation temperature 3650 °C.*

The carbon fibre is approximately 3 times stronger than similar steel wire. Noticeable is the very low specific electrical resistance and good thermal stability. These properties are considered to be very advantageous for the µEDM process.

3. Fabrication procedure of carbon fibre electrodes

To use carbon fibres as tool electrodes they must be specifically adapted. Because of their dimension and properties it is difficult to manipulate them and to machine a work piece. For the purpose of the experiments carbon fibre electrodes having a length shorter than 1 mm were fabricated - Figure 1.

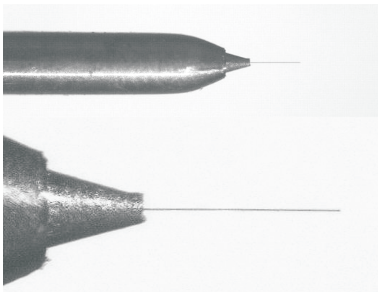

Fig. 1. Properly fabricated tool electrode with carbon fibre length ~0.7 mm.

The fabrication procedure was as follows: at first, a brass shank was prepared (ϕ1x20 mm); next, the shallow hole was drilled in the front of this shank. The obtained hole was filled with a soft alloy of good plasticity and electric conductivity. Then, a conical tip was formed mechanically. Afterwards, a microhole was drilled in the tip and a single carbon fibre was inserted. Finally, it was fixed into the tip by plastic deformation of the connecting alloy and the end of the fibre was trimmed - Figure 2. In the process of fabrication of electrodes the most difficult task was to achieve a provision of axial position and parallelism to shank surface.

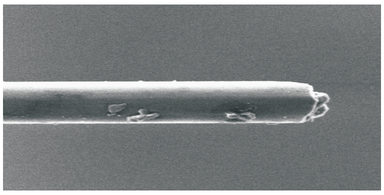

Fig. 2. Tip of a newly fabricated carbon fibre electrode.

4. Experiments

4.1. Initial successful trials with the use of carbon fibre electrodes

The first µEDM trials were conducted with short carbon fibre electrodes for sinking of microcavities - Figure 3. They revealed many problems, especially with regard to the provision of axial position of the carbon fibre. The material used in all experiments as a specimen was a gauge block of thickness of 1.33 mm made of hardened chromium steel GCr15. As a dielectric fluid cosmetic kerosene was applied. Independent variables were: voltage U, resistance R, capacitance C, polarity. Controlled variables included average current intensity of discharges I and in some cases total time of sinking t. Obtained cavities were identified by microscope observations and with the use of the Talysurf 10 Taylor Hobson measurement system intended for examination of micro-geometry of surfaces.

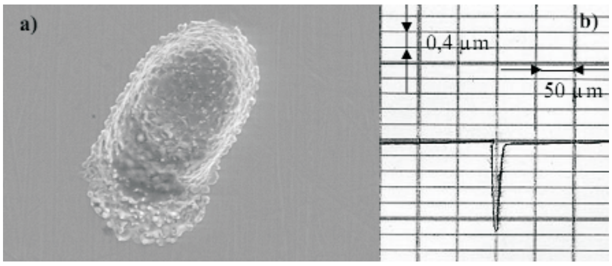

Fig. 3. Shape of microcavities machined by carbon fibre electrode, influence of electrode inclination (a), depth g=1.6÷2.4 µm (b) [4].

Next critical problem is erosive wear resistance - Figure 4.

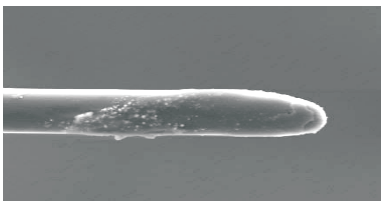

Fig. 4. Tip of 7 µm carbon fibre electrode after sinking.

According to Palatnik formula:

$$R_{ER} = C \rho \lambda_C T^2 \quad (1)$$

were:
C [J/(kg·K)] - heat capacity, ρ [kg/m^3] - density, λ_C [W/(m·K)] - thermal conductivity, T [°C] - melting temperature erosive wear resistance was calculated for electrode materials - Table 2.

Table 2. Erosive wear resistance according to Palatnik formula.

Material	Cu	W	Zn	Ni
R_{ER} (x10^9)	1620	6029	53.8	582

Erosive wear resistance (R_{ER}) calculated for carbon varies from 2.22·10^9 to 217·10^9 (depending on assumed values for carbon or graphite). This rate is much lower than on other electrode materials. Therefore, a solution for electroplating by Ni layer or other may be applied. It seems to be a promising concept for improvement of erosive wear resistance. Nevertheless, the diameter of tool electrodes is bound to be bigger than in the previous concept. Another solution would be a usage of longer electrodes supported by a special guide-eye. In this concept the electrode could be long enough to machine assumed length of cavity.

A further step is a quasi-continuous electrode made of a carbon filament to avoid the rapid wear problem - Figure 5. Such electrode could be long enough to machine cavities continuously.

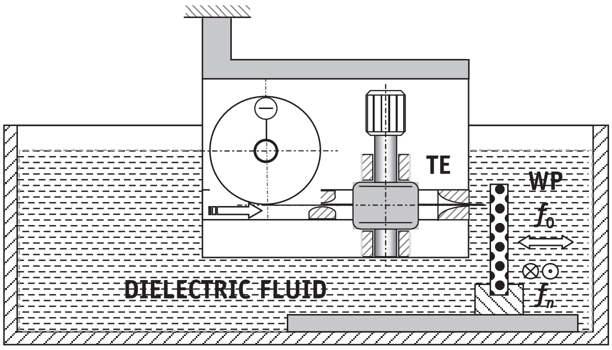

Fig. 5. Drive concept of quasi-continuous electrode.

4.2. Investigations concerning longitudinal sinking

These are not only round holes that are requisite in micro technologies. Some microelements must have special shape cavities. With the use of other materials as electrodes the kinematics of such process is similar to milling. With the use of carbon fibre as an electrode it is troublesome to machine such cavities due to its whippiness. Special procedures have been applied to machine the longitudinal cavity - Figure 6.

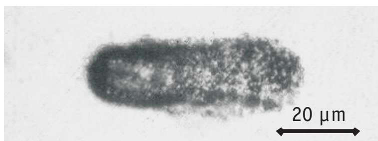

Fig. 6. Cavity after longitudinal sinking.

The procedure was as follows: sinking of electrode into low depth in the material and then another shallow hole very close to the previous one. In such a way that all round holes might connect with each other to create cavity. Parameters used in this experiment were U=100 V, R=22 kΩ, C=47 pF. The whole procedure took about 17 minutes.

4.3. Polarity of the carbon fibre electrodes

The experiments with reversed polarity were conducted to check whether the use of carbon fibres should have a significant influence on the efficiency. The tests have shown that reverse polarity (tool electrode as a cathode) - just like with the use of other electrode materials - has no beneficial influence on the process. The consumption of an electrode material proved to be higher and the efficiency of machining - lower in case of application of the reversed polarity. Parameters used in these experiments are presented in Table 3.

Table 3. Parameters used in tests.

No	U [V]	R[kΩ]	C[pF]	Polarity	Depth [μm]
1	100	22	47	reverse	1.2
2	120	22	47	reverse	2
3	120	22	47	normal	2.8
4	100	22	47	normal	1.7

4.4. Influence of the discharge energy on the process efficiency

Further experiments were conducted to find interdependence between discharge energy and process efficiency.

At first theoretical discharge energy was calculated. It was assumed that during discharge the energy constitutes about 0.7 of its calculated value. The theoretical value of energy was calculated on the basis of voltage and capacitance given for each trial with the use of the following formula

$$E=0.7\,\frac{CU^2}{2} \tag{2}$$

Over the test given parameters were distributed evenly. The resistance value of R=22 kΩ was constant.

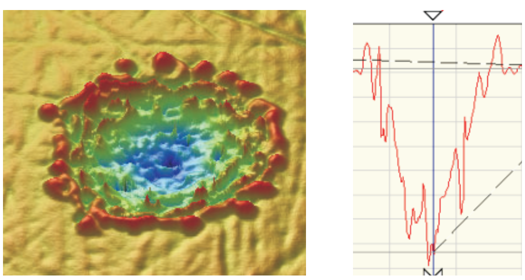

Fig. 7. 3D imagining and Profile of obtained cavity during the experiment.

Obtained cavities were identified with the use of a measurement system intended for examination of micro-geometry of surfaces (Veeco optical profilometer). Example of a cavity is shown in Figure 7. The edge of the cavity is very irregular. Due to a variety of sudden phenomena occurring during electrical discharge machining the electrode could vibrate at the beginning of the process. The bottom of the cavity is also uneven and very rough, so the measured depth of about 1.5 μm is only approximate.

The relationship between depth and applied energy is presented in Figure 8.

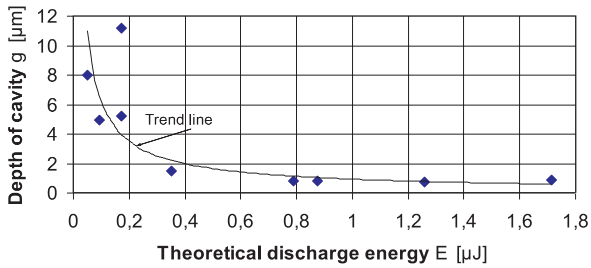

Fig. 8. Relationship between depth of cavity and applied energy.

In contrast with other electrode materials for the higher discharge energy the lower values of depth were obtained.

Nevertheless, it appears that in above discussed case a diameter of cavity as well as the time of effective machining should have also been taken into consideration. However, in the presented experiments only a total of time of sinking was measured with no regard of whether the effective machining took place, or not. Therefore, the obtained relationship can only be considered as an approximation and needs further detailed verification.

5. Conclusions

Conducted experiments lead to following conclusions.

The use of carbon fibres electrode is troublesome in preparation of short tool electrodes as well as because of low erosive wear resistance. Nonetheless, other properties seem to be adequate for EDM. Of particular advantage are such properties of carbon fibres as their small diameters and mass production. Preliminary experiments have shown that use of carbon fibres as tool electrodes could potentially find its application in μEDM. Conducted test showed that reverse polarity has no advantageous influence on the machining process. Investigations concerning longitudinal sinking reveal that a special procedure must be applied due to a whippiness of fibres. Owing to a very low erosive wear resistance it is essential to apply longer electrodes to the process. Possibility of using metal coatings or the system of continuous electrodes, which is now under investigation, seems to be very promising. This could prove to be the right solution to the problem of low erosive wear resistance and limited length of short electrodes.

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